GRANITE ISLANDS OF SOUTH-EAST VICTORIA AS A SEABIRD HABITAT

By Mary E. Gillham*

*Working in conjunction with the C.S.I.R.O. Wildlife Survey Section
[Communicated by J. A. Thomson 13 July 1961]

Summary

The principal rookery plants are halophytic, succulent creepers and tussocky monocotyledons, mainly *Poa poiformis*. Bracken and shrubs are less common. Penguins and shearwaters and other petrels burrow most plentifully in conditions of medium to great exposure; under rigorous exposure soil depth and vegetative cover are insufficient; in calm areas plant growth is too lush. The optimum burrowing medium is fairly sandy but not too mobile. Where lack of soil or unsuitability of soil texture makes burrowing impossible, birds may live under particular kinds of herbage.

The open vegetation and friable soils of mutton-bird rookeries constitute an ideal habitat for rabbits, but summer suppression of plants by the birds in the drier areas exerts a seasonal check to their numbers. A small rabbit population can complete the summer destruction of practically all vegetation except coarse, unpalatable tussocks and composites. On Rabbit I., where this had occurred, hundreds of mutton-birds died in the anomalous heat wave of January 1959. On ungrazed islands nearby the burrows were shaded by vegetation and there were few or no casualties. Serious predation by foxes occurs on Benison I., and the Gabo I. mutton-birds have been reduced to a fraction of their former numbers by feral cats.

Smaller petrels burrow among *Poa* on 2 of the Glennie I., and penguins occur on all but the 3 most sheltered islands in Corner Inlet. Silver gulls nest on 3 islands, their presence stimulating the succulent-leaved *Disphyma australe, Carpobrotus rossii* and *Lepidium foliosum*. The latter dominates a roost of black-faced cormorants on Granite I. where the ornithocoprophilous alga *Prasiola stipitata?* is frequent and constitutes the second record for Australia. Destruction and replacement of vegetation occur near ground-roosting and tree-roosting cormorants on Doughboy I. Cape Barren geese graze the Glennie Group, eating mostly *Disphyma australe* in the dry summer period.

Introduction

Descriptions of the 9 granitic islands that have provided data for this paper and lists of the vascular plants, bryophytes, and seabirds have been published elsewhere (Gillham 1961a).

Although the islands are edaphically similar, their degree of exposure to spray-bearing winds varies widely. Most exposed is the Glennie Group off the SW. tip of Wilson's Promontory (Citadel I., Dannevig I. and McHugh I.). Most sheltered are Doughboy I. and Benison I. in the muddy inner part of Corner Inlet N. of the Promontory. Between these two extremes are Cliffy I., 20 m. S. of Port Albert and 12 m. E. of Wilson's Promontory; Rabbit I., near the E. side of the Promontory, and Granite I., near the mouth of Corner Inlet (see locality map, Gillham 1960a).

Gabo I., 320 m. ENE. of the Wilson's Promontory islands near the Victoria-New South Wales border, is larger than the others, is composed of medium-grained red granite instead of porphyritic grey granite, and is the only one of the 9 to possess sand dunes and heath vegetation.

This paper deals with the principal environmental factors affecting the nesting and roosting habitats of the vast populations of seabirds that inhabit the islands and some of the ways in which the vegetation and soil affect the birds. Ways in which the birds affect the vegetation and soil are dealt with in a previous work (Gillham 1960a).

Most of the observations made apply equally well to Bass Strait rookeries farther S., in the Furneaux, King and Hunter groups of islands, except where the vegetation of these is periodically destroyed by burning, as on most of the commercial mutton-bird islands. Only in the higher rainfall areas of S. Tasmania and the hotter, drier climates to the N. of the region under consideration do conditions in the rookeries become materially different.

Typical Rookery Vegetation in Colonies of Burrowing Birds

In order to survive the rigours of seasonal occupation by birds, plants of the rookeries need to be resistant to heavy trampling, to introduction of atmospheric conditions underground in burrows, and to a high concentration of soil nutrients arising from guano deposition.

Most of the indigenous coastal heath plants are unable to cope with these conditions and give way to others that appear fairly constantly in rookeries from S. Tasmania to the New South Wales border—many of them also in New Zealand rookeries. The plants that persist best are often those that are also able to survive the soil disturbance of storm-swept, eroding coasts and the high concentration of soil salts arising from the deposition of seaspray. This results in the occurrence of coastal plants away from the coast and is especially well seen on Gabo I., where pockets of *Carpobrotus rossii* dotted through the inland scrub are indicative of outlying parts of the penguin colony. This phenomenon is seen also on British bird islands (Gillham 1956b).

Poa poiformis is the most widespread rookery species in SE. Australia and has a growth form that necessitates the birds going round the tussocks rather than over them, so that it suffers little suppression from trampling after the initial stages of growth. In densely populated rookeries the tussocks are widely spaced and the highways between them are worn bare of plants during the height of the nesting season. An analogy can be drawn with the dominant *Armeria maritima* of British shearwater rookeries, where burrows penetrate beneath the stabilizing mounds and tracks lead between them (Gillham 1956a).

Other tussocks providing similar habitat conditions on the Victorian islands are *Lepidosperma gladiatum, Lomandra longifolia, Scirpus nodosus,* and *Stipa teretifolia*.

Next in importance to the tussocky monocotyledons are the succulent creepers, principally members of the Aizoaceae (*Carpobrotus rossii, Disphyma australe, Tetragonia implexicoma*). Their creeping habit and method of anchorage enable them to withstand localized disturbance by burrowing. The high water content of the leaves serves to dilute excessive amounts of internal salts arising from concentration of the soil solution by guano, and also acts as a guard against wilting in habitats where air temperature and humidity in burrows among the roots may approximate to those of the atmosphere. Even so, both *Carpobrotus* and *Disphyma* were severely wilted on the Corner Inlet islands after an exceptional heat wave in January 1959.

Another important division of rookery plants might be termed 'bird evaders' in that they 'cash in' on the stored nutrients in otherwise unvegetated soil during the winter when the birds are at sea, but usually succumb to bird pressure and die during dry summers. These fall into two groups, exemplified on the one hand by small ephemeral grasses and caryophyllaceous plants, and on the other by more sturdy composites.

Most traces of the former group become obliterated by the end of the summer, but the stark remains of members of the latter group persist. The most conspicuous example on the SE. Victorian islands is the dead *Carduus tenuiflorus*, which forms open but almost pure stands in the Doughboy I. rookery from mid-summer onwards.

The tall inland form of *Senecio lautus* with finely divided leaves is common on the 3 sheltered Corner Inlet islands and in the protected N. valley of Rabbit I. It, too, died off in 1959, although it is usually perennial where unaffected by soil guano. The more usual bird-colony type, a short maritime form with very succulent, serrated or entire leaves, is very resistant to guano and able to persist throughout the breeding season. Some plants behave as perennials, others as annuals, but the autumn crop of seedlings becomes established while the young birds are still in the burrows.

Other composites coming into this division during hot dry summers but often persisting in cooler, moister seasons are *Cirsium vulgare, Helichrysum bracteatum* v. *albidum, Hypochoeris glabra, Leontodon hirtus, Senecio minimum, Sonchus asper* and *S. oleraceus*, and, on Victorian and Tasmanian islands other than the 9 under consideration, *Erigeron bonariensis, E. canadensis, Senecio capillifolius, S. glomeratus* and *Silybum marianum*. Not all of these behave as annuals, *Helichrysum* usually dying back only to ground level, even in a drought year, and *S. capillifolius* being more often biennial.

All the above genera (apart from *Helichrysum*) are represented in British rookeries, some by the same species; *Cirsium vulgare, Sonchus asper*, and *S. oleraceus* are particularly widespread. The most characteristic *Senecio* of British rookeries is the ragwort, *S. jacobaea*.

The prevalence of members of the Compositae in rookeries is probably related to the large area of bare soil, which offers ample space for the establishment of the efficiently dispersed disseminules. It is not uncommon to see clouds of thistledown, with or without attached seeds, drifting several miles out to sea and covering areas of several acres. The islands in the path of these clouds that show the most severe infestation, possibly only a year after being practically free from the species, are those where soil has been bared by bird traffic or overgrazing (assuming, of course, that adequate shelter is available).

Two important coastal life forms less characteristic of rookeries are bracken and shrubs. The interlacing underground rhizomes of *Pteridium esculentum* are an important deterrent to burrowing birds, which normally occupy only the sparser stands.

Burrows usually diminish beneath shrubs, particularly those of very exposed conditions where stunted branches form impenetrable ramifications close to ground level. Open-floored scrub is preferred and may be occupied as long as there is ready access to the sea, but the short-tailed shearwater is not found so typically in scrub as are species of the Queensland coast and New Zealand. Soft-leaved shade plants and sclerophyllous shrubs are easily destroyed by birds, so, when once established, the birds help to maintain an open ground layer beneath the trees.

Leptospermum laevigatum, a plant of both cliffs and dunes, is one of the most abundant rookery shrubs. Other important species are *Correa alba* and *Melaleuca ericifolia.* Frequently burrows in scrub are accompanied by growths of the succulent coprophiles, *Carpobrotus rossii, Rhagodia baccata* and *Tetragonia implexicoma.* These trail up through the branches of the shrubs, partially smothering the photosynthetic surfaces and probably hastening the degeneration already initiated by salt-bearing winds and bird damage (see Gillham 1960a).

Fig. 1 illustrates the principal plants in one of the most modified types of rookery and in one of the least modified. The histogram shows the percentage ground cover of plants on a belt transect across the sheltered top of Doughboy I. in Corner Inlet.

Excluding the portion beneath a clump of *Eucalyptus viminalis* trees, the first 28 metres of the transect were heavily burrowed by mutton birds. A lot of dark sandy soil with flakes of guano and granite chips in the surface layer was exposed and the vegetation was entirely altered. The dominant plant was the introduced *Vinca major,* the most generally distributed subordinate *Carduus tenuiflorus,* and the only other species of any importance *Senecio lautus.*

This area was fairly level and on deep soil with no outcropping rocks. Because of the open nature of the vegetation and the general collapsibility of the soil, frequent repairs to burrows were necessary and none of the area remained free from the effects of excavation

The cliff face rookery depicted in the last 6 metres of the transect consisted, on the other hand, of scattered burrows penetrating deeply beneath large boulders and scarcely affecting the scanty patches of vegetation between. Most of the area consisted of bare rock, and the only important plants were *Acaena anserinifolia* and *Pteridium esculentum.* Where burrow density increased on this cliff so also did *Vinca major.*

These two types of rookery were separated by a granite shoulder, where the soil was too shallow for burrowing. It was dominated by *Correa alba* in the rockier parts and by *Acaena* and small pasture species elsewhere.

Effect of Wind Exposure on the Burrowing Habitat

Excessive Exposure

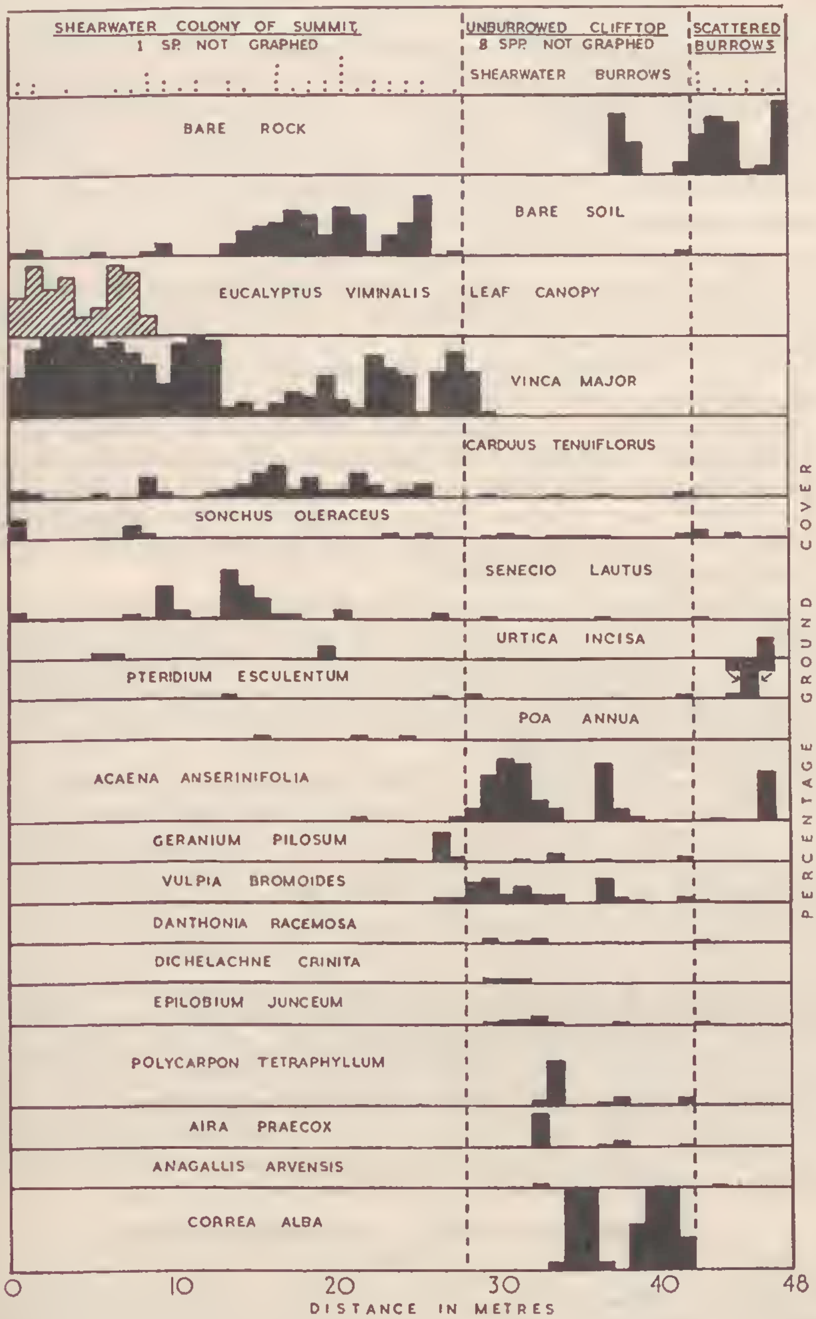
The range of exposure suffered in rookeries is wide, but the optimum appears to lie in fairly oceanic conditions where exposure could be classified as 'medium to great'. Where it is excessive the habitat becomes unsuitable.

On Citadel I., which is fully exposed to the S. and W., practically all soil has been swept into the sea during storms. The plants that survive the rigours of the habitat are too sparse and stunted to give cover to birds nesting without burrows, and the only suitable nesting sites are in rock crevices—situations favoured more by penguins than by mutton-birds.

Mutton-birds have had little more success on the exposed parts of Dannevig and McHugh I., where attempts to burrow in too shallow soil and too sparse vegetation are doomed to failure in consequence of frequent collapse of the thin burrow roofs.

In such areas an expanding colony of mutton-birds, with need to utilize every available nesting site, contributes in no small measure to the destruction of its own habitat, the burrowed soil eroding much more easily than the unburrowed.

Fig. 1—Doughboy I., Corner Inlet, 16 January 1959. Transect from SW. to NE. across summit colony of shearwaters to unburrowed clifftop with scattered nests below; 48 x 1 metres.



Sparse recolonization by plants helps to build up the level again, but the process is slow and subject to periodic catastrophies, so that completion of the cycle to bring the area back into the rookery takes a very long time.

The importance of adequate cover is well illustrated on the Cliffy I. Group, about 20 m. S. of Port Albert, which is almost as exposed as the Glennie Group. Soil and vegetation are sparse on Notch I. and White Rock, and mutton-birds are scarce or absent; adequate amounts of cover are confined on Cliffy I. to the small area on the summit where the birds congregate, and both soil and plants are more abundant on Rag I. and Seal or Direction I., where mutton-birds are reported to be numerous.

Excessive Shelter

At the other extreme are some localities on the Victorian islands that are too sheltered for adequate burrowing. In these a soft, lush vegetation excludes the birds from the burrowing medium and fails to attract them into the cover of its foliage as do more rigid xero-halophytes—possibly because of its greater power of surface water retention, possibly because of the stronger, more continuous growth, which obliterates all traces of nesting sites soon after they are vacated.

Both Doughboy and Benison I. are unusually sheltered for mutton-bird colonies and possess areas of dense vegetation untenanted and probably untenable by birds. Rookeries are common on the mainland coast of Tasmania, but all of those visited were adjacent to much more turbulent waters than the shallow, mud-floored, inner portion of Corner Inlet.

Of over 80 rookeries visited around Tasmania and Victoria only a small proportion occur on sand dunes, and these are almost exclusively on the mainland or larger islands. Mutton-birds of these inevitably more sheltered situations attain the necessary openness of vegetation as a result of edaphic rather than climatic factors. Where dense creepers occur locally it is not uncommon to find dead birds trapped among the tangle of stems.

On Benison I., where there are no dunes, the rookery is confined to the more exposed W. slopes. On Doughboy I. the main part of the rookery is so populous that most of the native perennial vegetation has been killed and much of what remains is transient, dying away in summer.

Examples could be cited of closely related shearwater species burrowing successfully in dense bush communities, but the density in these instances is of the tree canopy rather than of the plants in the vicinity of the burrows. The denser the canopy the greater is its capacity for shading and inhibiting the ground flora.

Thus the wedge-tailed shearwater (*Puffinus pacificus*) burrows in thick *Pisonia grandis* forest on islands of the Great Barrier Reef, where the coral sand beneath may be bare or covered by a 'leggy' growth of *Abutilon indicum*, *Euphorbia heterophylla* or *Wedelia biflora*. The sooty shearwater (*Puffinus griseus*) burrows in the soft peat beneath mixed evergreen bush on small islands off Stewart I. in S. New Zealand, where again the ground may be bare or occupied by open growths of large ferns, principally species of *Asplenium* and *Blechnum*.

Importance of Soil as a Burrowing Medium

Soil Mobility

The degree of soil mobility, as already indicated, has an important bearing on the longevity of rookeries on cliffs. It is an even more potent factor on dune sand, where burrow roofs collapse with extreme facility unless the sand is firmly bound by plant roots or rhizomes. Birds are unable to colonize the more mobile dunes, but occur beneath pioneer dune species such as *Ammophila arenaria* in fairly well vegetated regions.

The only mutton-birds in dune sand in the areas under consideration are a sparse population on Gabo I. and a few isolated pairs in the sand-filled valley of Rabbit I. Their relative scarcity in the latter, in spite of the fact that the remainder of the island carries a population close to saturation point (an average of about 2 burrows per sq. metre over the whole and up to 5-6 per sq. metre), is witness to the birds' inability to keep the burrows open in this type of substrate.

The extensive low sandhills that form the main part of the penguin rookery on Gabo I. are relatively stable and almost completely vegetated, except at burrow entrances and in the localized blowouts. The plant succession has passed the pioneering tussock phase and entered the stabilizing mat phase, and the dominant *Carpobrotus rossii* and locally dominant *Stenotaphrum secundatum* are among the most efficient of mat formers. Collapsed and silted burrows border the blowouts, and the opening out of the plant mat by the penguins has undoubtedly aggravated and probably initiated the erosion of these.

Where soil mobility on cliffs is accentuated by steepness of slope the birds insinuate their burrows beneath any available stabilizing agents such as tussocks, roots of isolated shrubs, or boulders.

Soil Consolidation

Just as considerable exposure, but not too much, is beneficial to burrowing birds, so is a high proportion, but not too much, of the mineral fractions contributing to soil friability. Too great a percentage of the clay and silt fractions facilitates 'poaching' to give a hard unburrowable surface and decreased permeability, so that burrows are liable to become waterlogged. It is well known that rabbits avoid the heavier clay soils. Shearwaters avoid them even more rigorously, but are not averse to taking over rabbit burrows in areas where it is improbable that they could have excavated their own.

No burrows were found on the partially waterlogged peat areas of Gabo I., although sooty shearwaters burrow freely in the peats of S. New Zealand and Macquarie I. Elsewhere all the SE. Victorian soils are freely draining sands with relatively small amounts of organic matter, offering no obstacle to burrowing birds.

Trampling by farm livestock may intensify the degree of consolidation to the detriment of the birds, but on Gabo I., the only one of the 9 islands on which stock were present, the rookeries are located on coarse 'unpoachable' sand, where the large particle size ensures a large pore space between. On such soil the trampling of dung and herbage into the surface layers is likely to be beneficial rather than otherwise.

Nesting Sites of Burrowing Birds on Unburrowable Soil

Numerous abortive attempts at burrowing were seen, the tunnels ending blindly against solid granite 30-40 cm from the entrance. Penguins not infrequently manage to rear chicks in these truncated burrows, but shearwaters sheldom seem to. It is problematical whether a second attempt is ever made at burrowing, and deserted eggs in inadequate holes were still fairly common at the end of January

1959, although most would have been taken by gulls and other predators soon after being laid about the last week of November.

It is in such localities that the more diffuse protection of herbage has often to suffice as a concealment for the nesting chamber, and it is as well for the occupants that trampling by farm livestock is not one of the habitat factors on the islands where such conditions occur.

In the most exposed areas, notably on Dannevig I., curtains of *Disphyma australe* draped across rock crevices give adequate protection to nesting birds, with *Tetragonia implexicoma* serving a similar function in areas of local shelter. With slightly mitigated exposure, as on the summit of Cliffy I., eggs are laid beneath the arched leaves of *Poa poiformis* tussocks. The larger tussocks of the more maritime *Stipa teretifolia* are also utilized, particularly by penguins.

With increased shelter, as on Granite and Benison I., birds insinuate themselves beneath mats of *Carpobrotus rossii* or growths of partially dead but still flowering *Pelargonium australe*, 30-60 cm high. On Doughboy I., whether shelter is sufficient for its survival, the trailing stems of *Acaena anserinifolia* roof some of the nesting chambers. Less permanent mats of *Holcus lanatus* function similarly in a few instances but are not favoured by the birds.

Erosion from Bird Tracks and Taking-off Points

During the nightly landfall at dusk airborne mutton-birds usually come to earth close to their burrows and have but a few metres of land travel to undertake before reaching them. Taking off just before dawn presents rather more problems, difficulty being experienced in becoming airborne unless there is a high wind.

On the smaller or more steeply sloping rookeries, such as that of Granite I., birds flap clumsily over the rookery surface and have gained sufficient momentum before reaching the sea. On larger or flatter rookeries certain elevated taking-off points are selected, and tracks converge on these from surrounding parts of the rookery. Often the take-off points are bare granite outcrops. If they are soil-covered the vegetation soon becomes worn down to a sparse, trampled carpet of hemicryptophytic grasses and herbs or disappears altogether.

Where no suitable eminences present themselves tracks lead right to the shore, the birds half flying, half running down their length and occasionally becoming airborne before reaching the sea.

This type of track is always used by the flightless penguins, which must walk both ways. Although well able to land on rocks, penguins prefer the ease of sandy beach landings and, where beaches are scarce, minor tracks from different parts of the rookery converge like the tributaries of a stream to form a main highway as much as 2 metres wide leading to a suitable beach.

It is possible to distinguish between mutton-bird and penguin tracks by the fact that all footprints point downhill on the former; on the latter, half point uphill although a proportion of these would have been obliterated during the most recent morning exodus. In many instances both species use the same tracks. Towards the end of the fledgling season the footprints on the upper parts of the mutton-bird tracks become confused because the young birds wander round at exercise outside the burrows during the hours of darkness.

Another distinguishing character is the degree of fouling on the tracks. It takes mutton-birds little time to flap down to the sea at dawn. For incoming penguins the track might be uphill all the way for a distance of several hundred metres. There are many pauses for breath, during which defaecation occurs.

The sandy soil is scuffled sideways and sent downhill, and the resulting depressions form natural run-offs for rain water, so that tracks may become scoured out deeply. They form an important erosion potential and are a particular hazard on the sandier soils.

The main track leading from the NE. rookery to the N. beach of Rabbit I. has started a long, narrow sand-blow, which is visible from the mainland several miles away as a yellow scar from summit to beach.

Tracks are most often bare of vegetation during the breeding season, but not infrequently show the dead remains of short-lived grasses and caryophyllaceous plants (e.g. *Poa annua, Vulpia bromoides, Cerastium glomeratum, Polycarpon tetraphyllum, Sagina* spp., and *Stellaria* spp.), which colonize them during the undisturbed winter period. Loose mats of the prostrate woody stems of members of the Aizoaceae sometimes cross the tracks, denuded of leaves where trampled but still supporting growth in the distal portions.

On islands such as Benison, where the routes are used only by mutton-birds, the downward track may diffuse outwards at the top of a steep slope, and birds flapping down the slope comb the trailing vegetation in a downward direction but exert insufficient pressure to destroy it.

Little clusters of coprophiles are frequently centred round the penguins' defaecation points, which are often on level patches above particularly steep and exhausting stretches.

Effect of Rabbits on Rookery Vegetation

Rabbits were often introduced on offshore islands by seamen as a potential source of food that could be utilized when the mutton-birds are not in residence, and even islands visited as seldom as the smaller Glennies have their quota. Only a few rabbits on an island such as Citadel, where the vegetation is so severely depressed by exposure and lack of soil, can be of serious consequence.

In retarding plant growth and the resultant soil accumulation, the rabbits help to prevent the area from maturing into a potential rookery, and burrowing birds are relegated to such rock crevices as are available. On Citadel I. it is likely that the habitat is too far from the optimum for removal of the rabbits to have any great or immediate effect. In the slightly less adverse environment of Dannevig I., however, their presence probably has an appreciable effect in slowing down extention of the rookery and hastening loss of rookery area by contributing to soil erosion.

These rabbit populations can never become large, because of the limiting effect of the meagre food supply in summer. The ecosystem has reached a low point of equilibrium, at its lowest in a dry summer such as 1959, where the rabbits keep the plants in check and the plants keep the rabbits in check.

The succulent leaves of *Disphyma australe*, one of the chief species of these habitats, are eaten by rabbits in reasonably sheltered conditions, but the stunted, red-leaved forms of the more exposed habitats are very salty to the taste and are not relished on these usually waterless islands. On Citadel I. the comparatively rare ferns and grass (*Asplenium obtusatum*, an unidentified member of the Polypodiaceae, and *Danthonia caespitosa*) are most severely grazed, and survive as a relict population in narrow crevices, where the tips of the leaves are eaten off almost as soon as they emerge. The much more abundant *Disphyma* is grazed, inevitably, but much of this grazing can be attributed to Cape Barren geese.

The most serious rabbit infestation is seen on Rabbit I. The estimated population there is small in relation to the total area, but large in relation to the amount of available food. The general impression is of an area which has been 'eaten out' and is carrying a residual rabbit population limited by the sparseness of food plants.

As not uncommonly with island populations in both hemispheres, the proportion of black rabbits is high; in fact all rabbits seen were black. All were feeding on the greener vegetation of the steeper cliffs and there were few dung pellets and fewer palatable plants in the rookery, which occupied the main part of the island. The wiry tussocks of *Poa poiformis* form the sole plant cover over most of the island during the summer breeding season and the locally associated plants of the sandier areas are as coarse and uninviting as the dominant. Those remaining in late summer are *Ammophila arenaria, Pteridium esculentum, Scirpus nodosus, Carduus tenuiflorus* and *Senecio lautus,* the two latter dead. In this rookery the soft, regenerating *Poa* shoots seemed to be the only source of food utilized. The leaves of a small patch of *Acacia longifolia* that persisted on the summit were seen to be eaten off as high as a rabbit could reach.

Most palatable species had retreated to the less accessible cliffs, where they formed a relict flora indicative of what the whole might have been in the absence of rabbits. 8 of the 10 species listed below as being found only in areas difficult of access are succulents, a group of plants favoured by herbivores, but of these *Bulbine semibarbata* and *Carpobrotus rossii* are normally grazed little if other food is available.

Relict flora of the less accessible cliffs:—

Agrostis avenacea	*Spergularia media*
Bulbine semibarbata	*Crassula sieberiana*
Disphyma australe	*Sambucus* sp.
Carpobrotus rossii	*Lobelia anceps*
Calandrinia calyptrata	*Cotula coronopifolia*

Soil depth is adequate for burrowing on Rabbit I., and destruction of so much of the plant cover by rabbits is not of serious consequence to the mutton-birds in a normal season. The year 1959 proved abnormal, however, and the detrimental effects of the heat wave on the birds was greatly accentuated by the paucity of shade resulting from the presence of rabbits.

In many cooler, moister areas of southern Tasmania and western Britain rabbits and shearwaters breed successfully side by side in the same warrens—even in different branches of the same burrows. There the effects of the rabbits are beneficial to the shearwaters rather than otherwise, in that they construct burrows often utilized later by the birds and eat down tall vegetation that is likely to choke the burrow mouths (Gillham 1955).

Since the depletion of the rabbits by myxomatosis and 1080 poison, a number of Tasmanian rabbit warrens have been taken over by expanding mainland populations of mutton-birds. There are, in fact, instances in the SE. of the State where the few surviving rabbits are reported to be ousted from the burrows by the returning birds in spring and forced to spend the summer lying up in the bracken, returning to the warrens in autumn when the birds go away to sea.

Effect of Heat Wave on Shearwaters in Two Types of Rookery

Many hundreds of shearwaters on Rabbit I. appeared to have succumbed to the exceptional heat wave of January 1959, when temperatures of as much as 110°F (43·3°C) were recorded on several consecutive days in Port Welshpool. Most of the victims were adult birds, but newly hatched chicks seemed not to have been affected, although the heat was still at its maximum when the island was visited on 18 January 1959 (108°F (41·1°C) at the lighthouse meteorological station on the SE. tip of Wilson's Promontory).

The dead birds lay, uninjured, in the mouths of their burrows or just outside. An oily, dark green splash on the ground beside most of them showed where the crop contents (studded with the black eyes of the small krill that formed the food) had been emptied prior to death.

As most of the burrows still contained eggs or newly hatched chicks, one of the adult birds was usually present. Had the heat wave fallen as little as a week later, when most of the birds were coming in only at night (Serventy 1958), they might have escaped unscathed.

The body-temperature of the adult short-tailed shearwater when incubating or brooding within the burrow is approximately 38°C (100·5°F), or 2-3°C lower than that of more active birds on the surface (Farner and Serventy 1959).

No facilities were available for measuring soil temperatures on Rabbit I., but Farner and Serventy, working in the Furneaux Group, Bass Strait, describe the burrow as providing a relatively stable micro-climate. They quote a diurnal temperature range in unoccupied burrows of 1-5°C (*c.* 2-9°F) as opposed to 15-30°C (*c.* 27-54°F) in the atmosphere, and a mean maximum burrow temperature during the period February-April inclusive of 20·5°C (69°F) in mid-February.

In western Britain it has been shown that, notwithstanding this mitigation of diurnal range as compared with that of the open air, the temperature and its fluctuations are much greater in and immediately adjacent to shearwater burrows than in soil of equivalent depth elsewhere (Gillham 1956a). Fluctuations of air temperatures within burrows are transmitted to the surrounding soil, and the time lag in loss of heat from the soil as compared with that from the air will serve to maintain high temperatures within the burrows well into the evening.

It is of interest in this matter that Specht and Rayson (1957) showed that in the warmer, drier conditions of SE. South Australia soil temperatures near the surface or unburrowed sands may be even higher than those of the atmosphere during the late afternoon in summer. Thus, when the air temperature had dropped to 29°C (84°F) at 4.30 p.m., the temperature at a depth of 3″ was 36°C (97°F) and at 6″ 30·5° (87°F). This 3″ maximum was 2·5°C (4·5°F) higher than the maximum air temperature, which was attained some 2-3 hours earlier.

In January 1951 the maximum soil temperature at a depth of 6″ in the South Australian soil was the same as the air temperature, and that at a depth of 3″ was 10°C (18°F) higher (36°C and 46°C, or 97°F and 115°F, respectively). At a depth of 12″ the temperature was only 6°C (11°F) lower than the air temperature (30°C or 86°F). Had shearwater burrows been present, it is likely that the high 3″ temperatures would have extended further below ground towards the nesting chambers.

These readings were made in open sandy areas such as were common on Rabbit I., and the temperatures obtaining on Rabbit I. during the January 1959 heat wave are likely to have been closer to the South Australian temperatures than to those with which Farner and Serventy were working. Where the sand was shaded by vegetation, Specht and Rayson recorded differences of up to 4·1°C (7·4°F) at depths of 3″ in summer.

Benison I. in Corner Inlet was visited 30 hours after leaving Rabbit I., when the heat wave was still in progress, but very few uninjured corpses or expectorated crop contents were seen there. Mauled carcases were present—as a result of predation—but there had been insufficient time for any wholesale killing, such as had occurred on Rabbit I., to have been masked by carrion-feeders. As Benison I. is a less oceanic habitat than Rabbit I., it is likely that temperatures there had been as high if not higher during the previous week, but the rookery is of a different type.

Benison I. has relatively little of the bare ground that is so prevalent on Rabbit I. between the *Poa* tussocks, the sun's rays being deflected in the main rookery by close mats of *Carpobrotus rossii* and tall stands of *Pelargonium australe,* and in marginal parts of the rookery by tall *Lomandra longifolia, Pteridium esculentum, Melaleuca ericifolia,* etc. The succulent leaves of *Carpobrotus,* like those of *Disphyma australe, Crassula sieberiana,* and *Dichondra repens,* were severely wilted, and the loss of water by transpiration would in itself have served to lower the temperature near the soil surface.

The severity of the heat wave in Corner Inlet may be judged by its catastrophic effects on species of the intertidal zone. Widespread death occurred among the two barnacle species, *Chamaesipho columna* and *Tetraclita purpurascens,* and the false limpet, *Siphonaria tasmanica,* while *Hormosira banksii* and *Zostera muelleri* were blackened and withered (J. Thomson pers. com.).

Marine life was seen to have suffered similarly on islands in Port Phillip Bay on 16 January 1960 during a similar heat wave with temperatures over the century mark. The burrowing birds on these islands (Mud I. and S. Channel Fort I.), however, were storm petrels (*Pelagodroma marina*). This species ranges farther north than *Puffinus tenuirostris,* and no deaths from heat were seen among either adults or chicks.

The rookery vegetation on Granite I. has a shading capacity intermediate between those of Rabbit I. and Benison I., and on 27 January 1959, dead birds and expectorated crop contents were far fewer per unit area than those seen on Rabbit I. This was, however, almost a week after the worst of the heat wave had passed, and none of the corpses remained intact. As it is not possible to distinguish between damage by predators and that by scavengers, deaths could not be attributed with certainty to heat—it can only be stated that dead birds were more abundant than was usual in the probable absence of mammalian predators.

The sensitivity of *Puffinus tenuirostris* to high temperatures may be indicated by the restriction of nesting colonies to SE. Australia. D. L. Serventy (pers. com.) states that breeding success is lower than average, for no apparent cause, in the most northerly part of the breeding range near Ceduna in South Australia, and it seems in the light of Victorian evidence that high temperatures may have some bearing on the matter; exceptional heat spelling a 'bad year' there, just as exceptional rain with its attendant flooding of burrows signifies a 'bad year' in Tasmania and Bass Strait rookeries. For every breeding adult killed there is a high likelihood that the dependent chick will also die.

Maintenance of a reasonable vegetative cover in the rookeries during the heat of the summer would thus appear to be most essential to *Puffinus tenuirostris* in regions where it is most difficult to achieve, viz., the marginal parts of the nesting habitat in South Australia and New South Wales.

Grazing in rookeries in the drier areas by farm livestock should be avoided where possible and, if carried out, should be limited to the winter and discontinued in time to give the plants a chance to regenerate before the return of the birds in spring.

Predation by Foxes, Feral Cats and Others

One of the most important predators of the mutton-bird, but fortunately a localized one, is the fox, which can create havoc in a small rookery in the course of a few nights. Of the 9 islands considered in this paper only Benison I. has a population of foxes, but foxes take a large toll of mutton-birds in more westerly parts of Victoria (e.g. Phillip I. in Western Port Bay, Griffith I. off Port Fairy, and Cape Grant near Portland).

Foxes reach Benison I. from Wilson's Promontory across the mud flats at low tide. The sandy beaches of the island were seen to be liberally imprinted with their tracks, while their dung was scattered throughout the rookery. Hundreds of dead mutton-birds lay around the island, some merely nipped at the back of the neck and left, others more extensively damaged—possibly by carrion-feeders subsequent to the initial attack. These were especially abundant at the open taking-off points, where the birds converged at dawn and where they would fall an easy prey to a waiting fox.

Carcases were not restricted to the rookery, many having been dragged into the cover of the scrub, some even into the lower branches of *Banksia integrifolia* trees. (It is conceivable that some of the latter had been eaten by scavengers after getting caught in the branches—a not uncommon fate of the shearwaters and petrels nesting in scrub—but all were in locations readily accessible to foxes.)

The cover afforded to foxes and/or feral cats by scrub might be a factor contributing towards the scarcity of occupied burrows in the denser cover.

Feral cats, offspring of domestic cats abandoned by former lighthouse-keepers, have worked havoc among the mutton-birds of Gabo I. A formerly large populations there had been reduced by 1959 to little more than 100 pairs surviving in small groups on the E. and W. coasts.

A large number of abandoned burrows were present in the E. coast rookery, wholly or partially overgrown by lush *Carpobrotus rossii*, and only about 40 burrows showed signs of recent occupation. Within this small rookery 30 dead mutton-birds were counted—a sufficiently high proportion of the total population to suggest that the colony was doomed to extinction during the next few years unless the cats were destroyed. 14 of the corpses had been dragged to an unburrowed peaty hollow about 6 sq. metres in extent on the island side of the rookery and were not on the birds' route to the sea, as were the aggregations of fox leavings.

(Extensive damage by feral cats occurs also in the Tasman I. rookery off SE. Tasmania, but this colony is still sufficiently strong to withstand fairly severe predation.)

Lighthouse-keepers on Cliffy I. reported that birds were more numerous in the small rookery there in 1959 than they had been in the few previous years, when a domestic cat and a dog had been preying on them. The colony still totalled fewer than 100, most individuals nesting in inadequate burrows or beneath grass tussocks, which afforded little protection from predators. Birds were more numerous on the adjacent uninhabited Rag I. and Seal I., where they were untroubled by domestic pets. The lighthouse-keepers had no knowledge of fairy prions, which had previously nested on the island but were not found in 1959, and these may have been exterminated.

Predation by man is difficult to assess, but undoubtedly occurs on many of the islands, particularly the inshore ones. Rabbit I. is reported by the local Fisheries and Wildlife Inspector (J. Rhodes) to be a popular, thought illegal, harvesting area for local holders of Tasmanian birding licences who fail to get as far as the Furneaux Group!

Mutton-birds are no longer found on Deal I. in the Kent Group further S., where carcases excavated by lighthouse-keeper C. Garreau from old rookeries have been identified as those of *Puffinus tenuirostris*, and this is believed to be an area where extermination has been effected by man.

There was no evidence of snake predation, although both black tiger snakes and copper-head snakes have been seen taking birds in other areas.

Nowhere were avian predators particularly numerous, and it is likely that the Pacific gull is the most important.

The raven (*Corvus coronoides*) was unusually abundant around Rabbit I. and the Corner Inlet islands in late January, having possibly been attracted by the large amount of carrion in the form of dead mutton-birds.

Other unusually abundant creatures on these inshore islands were the harlequin bug (*Dindymus versicolor*), which frequented the *Lavatera plebeja* with *Acanthocus trispinifer*, and a small brown bug belonging to the family Lygaeidae. The former, although a plant sucker, can be attracted experimentally by carrion (J. Thomson pers. com.); the latter is often associated with areas fouled by various types of seabirds elsewhere.

Colonies of Burrowing Birds Other Than the Short-tailed Shearwater

Petrel Colonies

All islands except Citadel I. possess colonies of short-tailed shearwaters (*Puffinus tenuirostris*), and the foregoing observations apply to rookeries of this species. Most apply equally well to the rookeries of other burrow-dwelling birds.

Small petrel burrows were found on only two of the Glennie Group—several hundred on Dannevig I. and possibly rather more on McHugh I. It is suspected that these belonged to diving petrels (*Pelacanoides urinatrix*) as dead birds of that species were seen on both islands, and a specimen from McHugh I. was identified by Dr D. L. Serventy. This appears to be the first record of that species for the Glennies.

On Dannevig, as on 8 white-faced storm petrel (*Pelagodroma marina*) islands visited in the Furneaux Group, the dominant *Poa poiformis* adopted a short, dense growth habit around the petrel burrows, forming a thick mat very different from the taller isolated tussocks of a shearwater rookery. On McHugh I. the burrows were mixed with those of shearwaters and penguins and the vegetation was of 'normal' rookery type.

A small number of fairy prions or dove petrels (*Pachyptyla turtur*) were reported by the Victorian Bird Observers' Club to nest on Cliffy I., but burrows of these were not seen.

Penguin Colonies

On 5 of the islands (Dannevig, McHugh, Cliffy, Rabbit, and Gabo) penguins (*Eudyptula minor*) and mutton-birds share the same territory, but penguins seem on the whole to have a slightly more oceanic distribution than mutton-birds. Penguins are present on Citadel I., where mutton-birds apparently do not occur because of the unsuitability of the severely exposed habitat, and are absent from the 3 sheltered Corner Inlet islands, where mutton-birds are abundant.

This type of distribution pattern is paralleled on Phillip I. farther W., where mutton-birds extend approximately 2½ m. farther up the W. coast into the more sheltered waters of Western Port Bay than do penguins.

Rookery vegetation is essentially similar with the two species, but the more drastic fouling outside penguin burrows when the young birds are present leads to greater destruction of indigenous vegetation and stimulation of transitory growths of coprophilous aliens.

Where many thousands of penguins burrow in the Gabo I. sand, the more usual arenicolous vegetation of tussocky, rhizomatous monocotyledons or dune shrubs has yielded place to the succulent and markedly coprophilous *Carpobrotus rossii*, a common plant in the more densely populated rookeries around Tasmania, and also in others less densely populated but where blown sea salt increases the high concentration of soil salts brought about by guano. In the N. of Gabo the *Carpobrotus* extends from coast to coast and farther S. it marks the occurrence of inland pockets of penguins in other vegetation.

Towards later summer much of the excess guano is washed away, but the burrows are still distinguishable by the accumulations of feathers from moulting birds. The burrows are frequently shorter and broader than the average mutton-bird burrow and sometimes are located in resistant substrata that might have proved untenable to mutton-birds.

Nesting Colonies of Silver Gulls

Silver gulls (*Larus novae-hollandiae*) nest on Cliffy I., Rabbit Rock and Granite I.

On Cliffy I., where about 100 pairs occurred on the N. slopes in the early summer of 1959, the nests were sufficiently diffuse for the vegetation to have been stimulated rather than otherwise by their presence. The dominant *Disphyma australe* (which is much the most characteristic species in colonies of surface-nesting seabirds in N. New Zealand (Gillham 1960b)) is generally dominant over the island as a whole, but it grew more vigorously in the gull colony. Production of anthocyanin was inhibited and the unusually green shoots grew erect at the tips to give a dense, moisture-retaining carpet 30 cm deep. The lush growth had obliterated most of the nests by 19 March 1959, and occupied 98% of the area, excluding granite outcrops. The only other species were *Calandrinia calyptrata, Lobelia anceps, Salicornia australis* and *Sonchus oleraceus*.

On Rabbit Rock the gullery was co-dominated by *Disphyma australe* and *Poa poiformis*. Crested terns (*Sterna bergii*) were present there.

It was estimated that rather more than 100 pairs of silver gulls nested on the lower S. slopes of Granite I. The guano-resistant *Disphyma* does not occur on this less oceanic island and the indigenous flora was severely depressed, although nests were widely spaced, usually several metres apart. The original sandy soil derived from the parent granite had become metamorphosed into an organic-rich clay impregnated with guano to a depth of 5-10 cm. As in the Gabo penguin colony, in the absence of *Disphyma* the closely related *Carpobrotus rossii* was dominant, but *Lepidium foliosum*, another ornithocoprophilous species, showed a marked local increase. Other species were *Bulbine semibarbata, Lavatera plebeja, Pelargonium australe, Poa poiformis,* and *Sonchus oleraceus.*

The following percentage frequencies of plants actually touching nests indicate that *Lepidium,* although not dominant in the area as a whole, might be more guano-resistant than the dominant *Carpobrotus,* and it is certainly a 'bird indicator' on the Bass Strait islands: *Lepidium* 65%, *Carpobrotus,* 35%, *Poa* 15%, *Sonchus* 5%.

The green leaves of a live *Poa* tussock had been bent over and woven together to form the fabric of one nest.

Food remains at the end of January, when some of the nests still contained eggs and young chicks, suggested that the crustacean *Squilla mantis* figured largely in the birds' diet at that season.

Cormorant Roosts

No nesting colonies of cormorants were seen, but areas frequented by both ground-nesting and tree-roosting species were examined.

Well over 100 black-faced or white-breasted cormorants (*Phalacrocorax fuscescens*) roosted on the N. end of Granite I. and their guano, which extended half-way to the summit, was visible from a distance of several miles. The most frequented rocks close to sea level bore thick deposits of guano and no vegetation. At the margin of this area tall, partially dead *Lepidium foliosum* was conspicuously dominant, and other more generally distributed species had been almost killed out.

Fig. 2 shows the histogram of a 6-yds-wide belt transect running from the lower limit of vegetation through the cormorant roost to the mutton-bird colony of the island summit.

Some depauperate *Poa poiformis,* the island dominant, survived in the roost, but most had been killed and the tussocks worn down to ground level by the trampling birds. Most of the small amount of *Carpobrotus rossii* had suffered a similar fate, and the other species present were the coprophilous *Senecio lautus, Lavatera plebeja,* and *Bromus diandrus.*

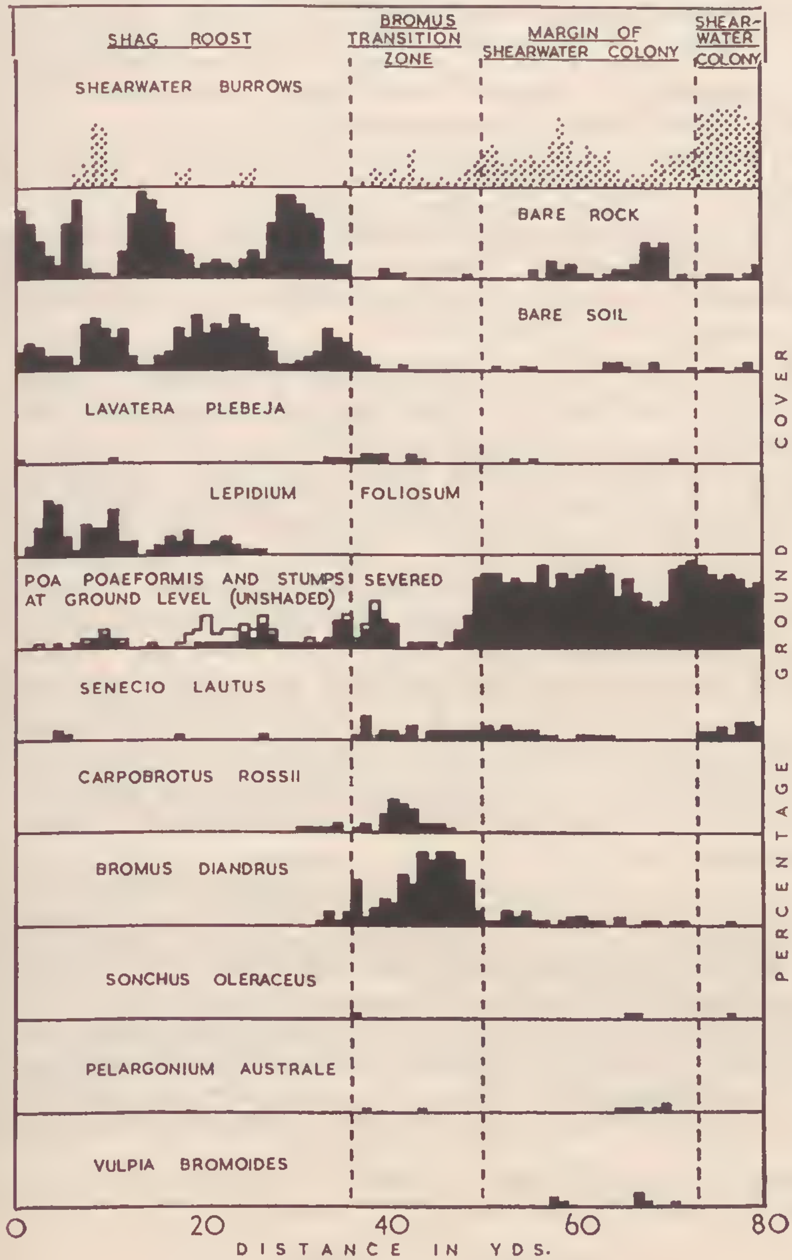
The last, although rare elsewhere on the island, became locally dominant in the transition zone between the *Lepidium* of the shag roost and the *Poa* of the shearwater rookery. Growth had formerly been very lush, but the plants were now dead and many of them trampled flat. This annual grass was a common winter invader of areas bared by birds in some of the Phillip I. rookeries.

Lepidium did not occur in the transect in the transition or mutton-bird zones, but the other, less markedly coprophilous species became progressively more abundant with increasing distance from the cormorants.

Mutton-bird burrows occurred in the guano-impregnated soil of the cormorant roost wherever it was sufficiently deep, but much of the area was rocky and the average burrow density in the *Lepidium* zone was only 0·3 burrows per sq. yd. In the Bromus transition zone it rose to 0·5 burrows per sq. yd., in the marginal *Poa* zone to 1·2 per sq. yd., and in the rookery proper to 2·7 per sq. yd.

The characteristically ornithocoprophilous green alga *Prasiola* was common on rocks in the transect area. Specimens from Granite I. (and from gull and cor-

Fig. 2—Granite I., Corner Inlet, 27 January 1959. Transect up NE. slope from 5 yds above HWM through shag roost to shearwater colony; 80 x 6 yds.



morant colonies in N. Tasmania) were determined by Dr H. B. S. Womersley as probably *P. stipitata*—these constituting only the second record for Australia. The previous specimens were collected by C. Beauglehole on the Lawrence Rock gannetry off Portland, W. Victoria, and it seems fairly certain that the genus is widespread on the bird islands of SE. Australia—as it is on bird islands of New Zealand (principally *P. stipitata*), Great Britain (principally *P. crispa*), and Macquarie I. (principally *P. crispa* ssp. *antarctica*).

The Cyanophyceae, members of which algal group are commonly present in guano-fouled rock pools near high-water mark in Britain, was here represented by a brown scum of *Lyngbya* sp. (Det. L. Osborne).

Black-faced and large black cormorants (*Phalacrocorax carbo*) roosted on rocks on the NE. side of Doughboy I. Again the heaviest fouling was on granite slabs below angiospermous vegetation, but it was sufficiently potent higher up to cause conspicuous modification of the vegetation.

The generally dominant *Pteridium esculentum* and *Correa alba* of the slopes above gave way to a transition zone of *Acaena anserinifolia, Sonchus asper* and *Vulpia bromoides,* and these, in turn, to pockets of highly guano-resistant species in the guano-saturated soil between rock outcrops.

The species suffering the greatest guano-deposition, and often with the entire photosynthetic surface coated with a hard layer of white excreta, were *Chenopodium glaucum* and *Poa annua*, the latter partially dead and a relict of an earlier, moister phase. Other ornithocoprophilous plants showing a local increase were *Carduus tenuiflorus* and *Urtica incisa*. Almost 50% of the 27 species in the upper part of the cormorant roost were aliens, some (e.g. *Euphorbia peplus* and *Leontodon hirtus* = *L. nudicaulis*) being seen only there; others (e.g. *Poa annua*) being associated also with mutton-birds but not being seen outside the rookeries.

Large black cormorants roosted in spindly, 3-metre-high *Melaleuca ericifolia* trees on the SE. of Doughboy Is. Some the trees had been completely killed, some partially killed, and all had thick coatings of guano adhering to the higher horizontal branches. Many of the smaller branches had been exfoliated or snapped off by the cormorants (cf. damage to trees in New Zealand cormorant colonies, Gillham 1961b).

Excreta lay ½-1 cm thick on the peaty soil beneath the trees and were sufficient to have caused a local change in the ground vegetation. As in the ground roost, the dominant bracken gave way to other species, only a few sickly fronds surviving, although this roost was on the inland side of the scrub patch. The 3 species that shared dominance in its stead were *Senecio minimus, Solanum aviculare,* and *Vinca major*. The *Senecio* was dead, as in the mutton-bird rookeries at the same season; the other 2 were green and thriving although heavily splashed with guano. Spindly, nitrogen-stimulated *Conchus oleraceus* showed a local increase where excreta was abundant. Mutton-birds burrowed in partially bare soil beneath these trees.

Kershaw et al. (1913) made no mention of cormorants being present when they visited the island in December 1912.

Grazing by Cape Barren Geese

Signs of Cape Barren geese were seen only on the 3 islands of the Glennie Group, and the largest flock was of only 15 birds on Dannevig I. As in the Furneaux Group, where flocks of several hundreds frequent some of the outer islands, their dung pellets were particularly abundant on granite outcrops that commanded wide views of the surrounding terrain.

No nests were found when the islands were visited in March, but the nests would have had ample time to disintegrate since they were vacated by the young birds several months previously and they were seldom seen at that season on islands where they were known to exist.

Large areas of *Disphyma australe* had been grazed—only the distal parts of the leaves being taken—and the swards were severely fouled in parts. Some of the less xeromorphic, broad-leaved *Poa poiformis* of crevices had been eaten, and fibrous remains in the dung suggested that this type of food, possibly collected over a wide feeding range, might figure more largely in the diet than was apparent from observation of the local vegetation. It was possible, however, that the succulent *Disphyma* leaf tips would leave few identifiable remains after passage through the alimentary canal, so that dung analyses would not prove to be a measure of species preferences.

Acknowledgements

My sincere thank are due to the following: C.S.I.R.O. Wildlife Survey Section and the Science and Industry Endowment Fund for the provision of research grants; the Commonwealth Department of Shipping and Transport, the State Fisheries and Wildlife Department, and Mr B. Munroe of Foster for the provision of boat transport; and Professor J. Turner and Dr D. L. Serventy for looking through the MS.

References

Farner, D. S., and Serventy, D. L., 1959. Body temperature and the ontogeny of thermoregulation in the slender-billed shearwater (*Puffinus tenuirostris*). *Condor* 61 (6): 426-33.

Gilliam, M. E., 1955. Ecology of the Pembrokeshire Islands. III. Effect of grazing on the vegetation. *J. Ecol.* 43 (1): 172-206.

———, 1956a. IV. Effects of treading and burrowing by birds and mammals. *J. Ecol.* 44 (1): 51-82.

———, 1956b. V. Manuring by colonial seabirds and mammals. *J. Ecol.* 44 (2): 429-54.

———, 1960a. Destruction of indigenous heath vegetation in Victorian seabird colonies. *Aust. J. Bot.* 8 (3): 277-317.

———, 1960b. Vegetation of tern and gannet colonies in northern New Zealand. *Proc. Roy. Soc. N.Z.* 88 (2): 211-234.

———, 1961a. Plants and seabirds of granite islands in south-east Victoria. *Proc. Roy. Soc. Vict.* 74: 21-36.

———, 1961b. Vegetation of New Zealand shag colonies. *Proc. Roy. Soc. N.Z.* 88 (3): 363-380.

Kershaw, F. E. S., et al., 1913. Excursion to the National Park, Wilson's Promontory. *Vict. Nat.* XXIX (11): 163-80.

Serventy, D. L., 1958. Recent studies on the Tasmanian mutton-bird. *Aust. Mus. Mag.* XII (10): 327-32.

Specht, R. L., and Rayson, P., 1957. Dark Island Heath (Ninety Mile Plain, South Australia). I. Definition of the ecosystem. *Aust. J. Bot.* 5 (1): 52-75.